y. Viro
4.3.98

RECONFIGURATION CONTROL SYSTEM FOR AN AIRCRAFT WING

Ins. B'

BACKGROUND OF THE INVENTION

The present invention relates generally to aerodynamics and, more particularly, to a reconfiguration control system for optimizing the spanwise lift distribution on a blended wing-body aircraft by reconfiguring the deflection of trailing edge control surfaces.

There are primarily two types of aircraft configurations: the more common configuration which includes a tail section comprised of vertical and horizontal stabilizers located at the aft end of a tubular fuselage; and the tailless configuration. As to tailless aircraft, there are two sub-types: a first type which has no central body, commonly known as a "flying wing," and a second type having a central body which is blended into laterally extending wings.

Tailless aircraft possess the advantages of inherently lower weight and drag than a comparatively sized conventional aircraft having a fuselage and tail section. Several features of tailless aircraft effect these advantages. First, the need to enclose payloads in the wing results in thicker airfoil sections that are efficient at resisting bending loads, thereby lowering the necessary structural weight. Second, payload and fuel are distributed in the spanwise direction, which shifts the weight closer to where the lift is generated, thus reducing the structural loads that must be carried. Third, elimination of horizontal and vertical tail surfaces reduces the aircraft's wetted area and thus reduces parasite (skin friction) drag. These advantages have enticed aircraft designers to consider tailless configurations for a variety of military and commercial applications.

Tailless aircraft have several shortcomings that have frustrated those who seek to realize the significant advantages offered by this design. Because tail moment arms (the distance between the control surfaces and the center of gravity) are shorter, greater changes in local lift may be required to trim the airplane through different flight conditions. Deflecting control surfaces to trim the aircraft usually changes the spanwise lift distribution in a way that increases induced drag (drag from vortical energy imparted to the air in the process of generating lift).

Furthermore, tailless aircraft are more sensitive to shifts in location of the center of gravity along the longitudinal axis than are conventional aircraft having fuselages

and tail sections. A shift in the center of gravity could be caused during flight by the use and transfer of fuel or by the movement of passengers and cargo. While conventional aircraft adjust to shifts in center of gravity with minimal change in wing lift distribution and drag characteristics, tailless aircraft require substantial changes in lift distribution that have a corresponding impact on drag. This presents a somewhat intractable problem that has impeded the development of a commercial airliner having a tailless design.

Based on the foregoing, it can be appreciated that there presently exists a need for a tailless aircraft which overcomes the above described shortcomings of the tailless aircraft of the prior art and which enhances the aerodynamic and weight advantages inherent to a tailless design. The present invention fulfills this need in the art.

SUMMARY OF THE INVENTION

The present invention encompasses a system to reconfigure the control surfaces and the resulting spanwise lift distribution of a blended wing-body aircraft, to optimize its aerodynamic characteristics in a number of flight regimes. Independently deflectable control surfaces are located on the trailing edge of the wing of the blended wing-body aircraft. The amount and direction of the deflection of each control surface has been determined so as to optimize the spanwise lift distribution across the wing for

each of a variety of flight conditions. The control surfaces are accordingly deflected and reconfigured to their predetermined optimal positions when the aircraft is in each of the aforementioned flight conditions. Optimal control surface reconfigurations have been respectively calculated for the flight conditions of cruise, pitch maneuver, and low speed.

With respect to cruise, the control surfaces are reconfigured to achieve a spanwise lift distribution that optimizes the lift to drag ratio while maintaining the aircraft at a trimmed angle of attack. Only minimal deflections of control surfaces are necessary because the wing's baseline design is for optimal performance at the cruise condition. Moment

In a pitch maneuver, the control surfaces are deflected to pitch the nose up or down, which increases loading on the wing frame. The control surfaces are reconfigured to achieve a spanwise lift distribution that minimizes the increased bending moments (about the bending axis) that necessarily result from increased loading on the wing. Minimizing the bending moments is desirable because increased bending moments require stronger aircraft structures, which means larger and heavier aircraft structures. The minimization of bending moments is achieved by deflecting the control surfaces to effect increased inboard lift in conjunction with decreased lift near the wing tips. Additionally, the deflected control surfaces provide the aircraft with additional pitch trim necessary for a pitch maneuver.

The primary considerations for low speed conditions (e.g., takeoff and landing) are maximizing lift and maintaining trim. At low speeds, the control surfaces are configured to improve maximum lift and delay stall while simultaneously trimming the airplane. Control surfaces are deflected downward in stall critical regions, increasing the maximum lift of those sections. In regions that are not stall-critical, control surfaces may be deflected upward to trim the airplane.

BRIEF DESCRIPTION OF THE DRAWINGS

These and various other features and advantages of the present invention will be readily understood with reference to the following detailed description read conjunction with the attached drawings, in which:

Figure 1 is a schematic drawing of a conventional aircraft of the prior art having a tubular fuselage and an appended tail section which includes a vertical stabilizer and a horizontal stabilizer;

Figure 2 is a schematic drawing of a tailless aircraft of the prior art;

Figure 3 is a perspective view of a blended wing-body aircraft incorporating the reconfigurable control surface system of the present invention;

Figure 4 is a perspective view of one side of the blended wing-body aircraft incorporating the reconfiguration control surface system of the present invention;

Figure 5 depicts the reconfiguration of the control surfaces and the spanwise lift distribution for cruise;

Figure 6 depicts the reconfiguration of the control surfaces and the spanwise lift distribution for a pitch maneuver; and

Figure 7 depicts the reconfiguration of the control surfaces and the spanwise lift distribution for maximum lift at low speed.

DETAILED DESCRIPTION OF THE INVENTION

An exemplary conventional aircraft **20** having a tail section is schematically depicted in Figure 1. Aircraft **20** includes tubular fuselage **21,** wing **23,** horizontal stabilizer **25,** and vertical stabilizer **27.** When loaded, aircraft **20** has center of gravity **29.** Horizontal stabilizer **25** controls the rotation of aircraft **20** about the pitch axis passing through center of gravity **29.** Vertical stabilizer **27** controls the rotation of aircraft **20** about the vertical, or "yaw," axis passing through center **of** gravity **29.**

The vector L represents the lift generated by wing **23.** The additional lift

generated by fuselage **21** is small in comparison to the lift generated by wing **23,** and will be ignored herein. The vector l represents the lift generated by horizontal stabilizer **25** and is adjusted as necessary to stabilize the pitch moments of the aircraft. The presence of horizontal stabilizer **25** and vertical stabilizer **27** contributes a significant component to the total drag coefficient for aircraft **20.**

Another drawback inherent to aircraft **20** is the weight of fuselage **21.** Fuselage **21** is present primarily to carry payload. Secondary functions of the fuselage are to provide a pitch moment arm of sufficient length to allow the pitch rotation of aircraft **20** to be controlled by the lift l generated by horizontal stabilizer **25** and to provide a yaw moment arm of sufficient length to allow the yaw rotation of aircraft **20** to be controlled by the force vector generated by vertical stabilizer **27.**

Also, the conventional aircraft design demands that the wings sustain large bending moments. The wings experience large bending moments because a substantial portion of the weight of the aircraft is located in the fuselage, due to payload location and structural weight. Yet, the majority of lift generated by the aircraft is located on the wings. Wing **23** must, therefore, be designed to withstand the bending moment induced by the difference in centers of lift and weight, in addition to the forces and moments created by aircraft maneuvers. Strengthening of the wing requires more structural weight than would otherwise be called for, leading to higher take-off weights.

The drawbacks inherent to conventional aircraft designs exemplified by aircraft **20** have led aeronautical engineers to consider tailless designs. A perspective view of an exemplary tailless aircraft **30** is schematically depicted in Figure 2. Aircraft **30** includes deflectable reflexes **33**, deflectable control surfaces **35**, trailing edge **37**, center of gravity **38**, and center of pressure line **39**. Reflexes **33** and control surfaces **35** are located in the trailing edge **37**. Moreover, reflexes **33** are the most outboard of the deflectable control surfaces. Line **39** is the locus of the centers of pressure for the respective chordwise cross sections taken along the span of aircraft **30**.

The flight of tailless aircraft **30** is controlled and stabilized by the appropriate deflections of control surfaces **35** and reflexes **33**. Upward deflection of the control surfaces **35** moves the center of pressure for the entire wing forward, generating pitching moments that rotate the nose of the aircraft **30** in an upwardly direction. Similarly, downward deflection of the control surfaces **35** moves the center of pressure for the entire wing in an aft direction, generating pitching moments that rotate the nose of the aircraft in a downwardly direction. The steady-state angle-of-attack resulting from deflection of the control surfaces **35** depends upon the stability of the aircraft **30**.

At forward center-of-gravity, the aircraft **30** will generally be in a stable configuration, with the lift due to angle-of attack generating nose-down pitching moments that must be countered by a net upward deflection of the control surfaces **35**.

When in an aft center-of-gravity configuration, the aircraft **30** is potentially unstable, with the lift due to angle-of-attack generating nose-up pitching moments that must be countered with a net downward defection of the control surfaces **35**. When in such an unstable condition, the control system will deflect control surfaces **35** in an upward direction to pitch the aircraft **30** to the desired angle-of-attack and then deflect control surfaces **35** in a downward direction to maintain the angle-of-attack. The differences in controlling the aircraft **30** at forward and aft center-of-gravity provokes consideration of both conditions in determining the control surface deflection scheme. Reflexes **33**, lying aft of the center-of-gravity **38** and having the longest pitching moment arm of all the control surfaces, are most effective at trimming the aircraft **30** to the desired angle of attack.

As may be discerned by cursory inspection of Figure 2, tailless aircraft **30** has no horizontal and vertical stabilizers projecting into the ambient airstream, and thus has lower parasite drag than conventional aircraft **20.** Moreover, since the flight of tailless aircraft **30** is controlled and stabilized without horizontal and vertical stabilizers, it does not utilize the moment arm to the aforementioned stabilizers otherwise provided by a fuselage/ The absence of a fuselage further lowers the drag coefficient and weight of tailless aircraft 30 in comparison to conventional aircraft **20.** Wing section **31** of tailless aircraft **30** may weigh less than wing **23** of aircraft **20** because the distribution of the structural and payload weights oppose the lift in such a way to reduce the bending

moment.

Although tailless aircraft provide the aforementioned advantages over aircraft having a conventional fuselage and a tail section, tailless aircraft suffer from at least one major shortcoming. Namely, for tailless aircraft **30**, the pitch moment arm from center of gravity **38** to the lift vector l generated by reflexes **33** is shorter than the corresponding pitch moment arm for aircraft **20** between center-of-gravity **29** and the negative lift **l** generated by horizontal stabilizer **25.** This renders aircraft **30** more sensitive to changes in the longitudinal station of center-of-gravity **38,** for example, due to a shift in the location of cargo or fuel during flight, or the placement of cargo during loading on the ground. Alternatively stated, the aerodynamic envelope for stable and controlled flight for tailless aircraft **30** is narrower and thus will tolerate less movement of loaded center-of-gravity **38,** in comparison to the wider envelope for conventional aircraft **20**. This characteristic makes it more challenging to design a tailless aircraft.

Figure 3 is a perspective view of blended wing-body aircraft **41,** which incorporates a control surface reconfiguration system **43,** which constitutes a preferred embodiment of the present invention. Although the preferred embodiment of the present invention is implemented in a blended wing-body aircraft, it could also be used to optimize the aerodynamic characteristics and reduce the weight of a conventional wing on a conventional aircraft having a tubular fuselage and an appended tail section,

such as aircraft **20.**

Figure 4 is a perspective view of the half of aircraft **41** located on one side of longitudinal axis of symmetry **45.** The remaining half of aircraft **41** is the mirror image of that shown in Figure 4, and is omitted for the sake of brevity. Aircraft **41** includes six deflectable control surfaces: **47, 49, 51, 53, 55,** and **57.** The aforementioned control surfaces are independently deflectable, and located on the trailing edge of aircraft 41. The present invention is not limited to any particular number or spanwise location of control surfaces.

An optimum reconfiguration of control surfaces **47, 49, 51, 53, 55** and **57** has been calculated for each of four flight conditions: cruise, forward and aft center of gravity pitch maneuvers, and maximum lift at low speed.

Cruise

For the cruise condition, the control surfaces are reconfigured to maximize the lift to drag ratio and to keep the aircraft trimmed at a stable angle of attack. The optimal lift distribution minimizes compressibility drag and lift-dependent viscous drag. As shown in Figure 5, this is accomplished with only slight downward deflection of each of the control surfaces because the wing's baseline design is for optimal performance in this condition. The resultant spanwise lift distribution is also shown in Figure 5.

Pitch Maneuver

The deflections of the respective control surfaces for the pitch maneuver condition are shown in Figure 6. The inboard control surfaces **47** and **49** are deflected appreciably downward to generate significant lift; control surface **51** remains undeflected; control surface **53** is deflected slightly downward; and outboard control surfaces **55** and **57** are deflected upward to reduce lift. The lift generated by this configuration trims aircraft **41** at an increased angle of attack and corresponding increased total lift. However, the extent of inboard and outboard control surface deflections necessary to trim the aircraft will depend on the center of gravity location.

Figure 6 also shows a typical spanwise lift distribution generated by the control surface deflection configuration of the present invention. The foregoing deflection reconfiguration causes the bending moment about axis of symmetry **45** caused by the lift for this maneuver to be less than the bending moment if the same lift was obtained using the conventional deflection reconfiguration of the control surfaces. This is because the lift is obtained by downwardly deflecting inboard control surfaces **47** and **49** a significant amount, while upwardly deflecting outboard surfaces **55** and **57** a lesser amount. The reconfiguration of the present invention takes into account the longer moment arms for outboard control surfaces **55** and **57,** in comparison to the shorter moment arms for inboard control surfaces **47** and **49.**

The reduction of the bending moment acting on the wing allows the wing structure to be designed with less strength than would be the case if a conventional reconfiguration of the control surfaces were used, and the weight of the structure can be concomitantly reduced.

Low Speed

Figure 7 shows the control surface reconfiguration for maximum lift in a low speed condition, such as occurs during landings and take-off. Inboard control surfaces **47** and **49** and outboard control surfaces **53, 55,** and **57** are deflected downward an appreciable amount to increase the maximum lift at stall-critical regions. Only control surface **51** is deflected upward to trim the aircraft. For some combinations of wing configuration and flight condition fewer stall-critical regions exist, resulting in the need for fewer downwardly deflected control surfaces. In such cases, more control surfaces may be deflected upward to trim the aircraft, achieving trim with lower deflection angles and lower drag.

Examples

As an example, the control surface deflections called for by the reconfiguration control surface system of the present invention were calculated assuming its use on a blended wing-body aircraft having the parameters set out in Table 1. Table 2 sets out the deflections which will provide optimal performance in each of the noted flight

conditions. In accordance with common convention, a positive deflection is downward, and a negative deflection is upward. This example assumes that no slats are included on the leading edge.

TABLE 1

range	**6286 nautical miles**
lift to drag ratio	**23.0**
cruise e	**0.70**
cruise angle of attack	**2.9·**
maneuver angle of attack, aft center of gravity	**3.9·**
maneuver angle of attack, forward center of gravity	**4.9·**
landing angle of attack	**17.8·**
cruise SM	**-0.18·**
landing SM	**0.05·**

TABLE 2

% ½ span	**0.0**	**9.1**	**22.7**	**40.9**	**59.1**	**77.3**	**100.0**	**0w**	**100w**
inc.	**0.0·**	**0.0·**	**2.3·**	**2.8·**	**-3.6·**	**-1.0·**	**3.6·**	**2.0·**	**1.0·**
cruise	**8.0·**		**-2.8**	**0.8**	**4.5**	**0.7**			
aft center of gravity	**19.5**		**-7.0**	**1.9**	**11.0**	**1.7**			
forward center of gravity	**-2.6·**		**0.9·**	**-0.3·**	**-1.5·**	**-0.2·**			
high lift, low speed	**-15.0·**		**-15.0·**	**-8.8·**	**4.7·**	**5.6·**			

The use of the deflection configurations of the present invention is not limited to a blended wing-body aircraft or conventional wing that does not have leading edge slats. Indeed, it was determined by theoretical calculations that the cruise performance of a blended wing body aircraft using the control surface configurations of the present invention was compromised without slats. Theoretical calculations which incorporated leading edge slats from 59.1% semi-span to the outboard wing tip indicate that the use of such slats provides a more efficient cruise spanwise lift distribution using minimal deflections of the trailing edge control surfaces.

A second illustrative example was calculated using slats on the leading edge of a blended wing-body aircraft having the parameters set out in Table 3. Table 4 sets out the control surface deflections which will provide optimal performance in each of the noted flight conditions. In accordance with common convention, a positive deflection is downward, and a negative deflection is upward.

TABLE 3

range	7378 nautical miles
lift to drag ratio	27.7
cruise e	0.94
cruise angle of attack	4.1·
maneuver angle of attack, aft center of gravity	5.2·
maneuver angle of attack, forward center of gravity	6.2·
landing angle of attack	18.1·
cruise SM	-0.19·
landing SM	0.06·

TABLE 4

% ½ span	0.0	9.1	22.7	40.9	59.1	77.3	100.0	0w	100w
inc.	0.0·	0.0·	-1.3·	-0.7·	0.4·	1.5·	2.0·	1.8 ·	1.5·
cruise	-1.8·		0.6	-0.8	0.1	-0.4			
aft center of gravity	11.0		-3.8	4.6	-0.3	2.5			
forward center of gravity	-13.3		4.5	-5.5	0.4	-3.0			
high lift at low speed	-13.9		13.9	11.3	-27.8	-27.8			

Although a presently preferred embodiment of the invention has been described in detail hereinabove, it should be clearly understood that many variations and/or modifications of the basic inventive concepts taught herein which may appear to those skilled in the pertinent art will still fall within the spirit and scope of the present invention as defined in the appended claims.